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PRIMARY POWER AND POWER DENSITY ANALYSIS.(U)
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TECHNICAL MEMORANDUM TM-775

PRIMARY POWER AND POWER DENSITY ANALYSIS (U)

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TECHNICAL MEMORANDUM

Primary Power and Power Density Analysis

This memorandum presents a simplified analysis of the active system power requirements for new submarine sonar. The analysis was performed in the new submarine sonar group for the purpose of indicating approximate primary power and transducer design requirements. These data are presented in this form because it is believed the information is useful to others of NEL and to a few persons and activities outside NEL.

The primary power and the power density¹ required to produce a specific source level are functions of the geometry of the array, the efficiency of power conversion and the characteristic impedance of the water. The efficiency of power conversion is the product of efficiencies of the transducer and the power amplifier. The effect of the ordinary variation in the impedance of the ocean is insignificant.

Initial Assumptions

Let us assume an eighteen foot diameter spherical shell array uniformly covered with transducers. In the trade-off between the delay necessary to form a beam and the vertical directivity achievable, it appears that the selection of a 120-degree sector of the sphere as the vertical array dimension is near optimum. Furthermore, we assume that the array when operated omnidirectionally, produces the standard source level of 71.6 db re 1 μ bar at a distance of one yard per watt of radiated acoustic power.

- (1) the ratio of electrical power into the transducer to the transducer radiating area.

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Convergence Mode Fan Beam

At present, it appears feasible to obtain a six degree vertical beamwidth with 120 degrees of vertical active area on an eighteen-foot sphere. Because the submarine pressure hull eliminates approximately sixty-degrees of hindsight, a desired omnidirectional transmission is reduced to approximately 300-degrees. Table 1 is a listing of primary power (P) and the power density (W) (measured at the input to the array) versus the total efficiency of the transducer/amplifier combination for a source level of 141 db.

Total Efficiency	.10	.15	.20	.25	.30
Primary Power (Megawatts)	3.8	2.5	1.9	1.5	1.3
Power Density (kw/sq. ft)	1.6	1.3	1.1	1.0	0.9

Table 1.

(Requirements to produce a fan-shaped beam 300° in azimuth by 6° in vertical)

Convergent Mode Conical Beam

Next, we determine the primary power required to produce a six degree conical beam. A radiating area defined by a 120° cap on an 18 ft diameter sphere is assumed. As before an efficiency range from .10 to .30 is considered. The computations are made for three source levels, namely 141 db, 145 db, and 150 db. These correspond to the source levels required for convergence, direct path, and bottom bounce, respectively.

Table 2 summarizes the results.

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		Primary Power (in megawatts)				
Source Level (in db)	Total Efficiency					
		.10	.15	.20	.25	.30
141		.06	.04	.03	.024	.02
145		.15	.10	.075	.06	.05
150		.48	.32	.24	.17	.16

Table 2.

(Power required to produce a 6° conical beam)

The decrease in primary power required for a six degree conical beam over that for an omnidirectional transmission is due to the increased directivity of the conical beam.

Bottom Bounce Mode Fan Beam

In the bottom bounce mode, another trade-off is made in order to determine the beamwidth (vertically). A beam ten degrees in vertical width appears to be broad enough to give reasonable coverage yet narrow enough to be free of excessive reverberation effects. Again, a fan extending 300 degrees in azimuth is assumed because of the hull. Using the source levels and efficiencies, as for the conical beam case above, the primary power and the power density as a function of depression angle were determined. A plot of power density*(considering only the lowest and highest efficiency values) versus the depression angle is shown in figure 1, for the three source levels (141, 145, and 150 db re μ bar at 1 yard).

*See addendum

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Figure 2 is the power density-efficiency spectrum versus depression angle for a single source level (141 db).

Table 3 is a listing of primary power versus source level and efficiency for zero degree depression angle.

Source Level (in db)	Total Efficiency	Primary Power (in megawatts)				
		.10	.15	.20	.25	.30
141		6.3	4.2	3.2	2.5	2.1
145		16	11	8.0	6.4	5.3
150		50	34	25	20	17

Table 3.

(Power required to produce a fan beam 300° in azimuth and 10° in vertical)

Calculations

The equation used for the calculations of primary power is:

$$P = \left[\log^{-1}(S - 71.6 - D)/10 \right] / (E_{TOT})$$

The directivity index, D, was approximated by:

$$D = 10 \log \frac{4\pi}{\Omega}$$

where Ω is the solid angle defined by the 3 db down points of the main lobe. For directivity patterns with well suppressed side lobes this approximation is sufficiently accurate.

It can be shown that the value of the standard source level (71.6 db) actually changes only a few tenths of one percent for the normally encountered changes in characteristic impedance.

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For the convergence mode fan beam and the conical beam calculations, a slide rule was considered sufficiently accurate. The data for the bottom bounce mode fan beam was generated by a computer program on the USQ-20 (via TACT). The program equations are:

$$P'' = \log^{-1} \left[(S - 71.6 - D)/10 \right]$$

$$D = 10 \log \left\{ 2\pi / \left[\phi (\sin \theta_0 / 2 \cos \alpha) \right] \right\}$$

$$W = P'' / (A \cdot E_{TOT}^{1/2})$$

$$A = r^2 \phi (\cos \theta_1 + \cos \theta_2)$$

$$\theta_1 = \alpha + \frac{(\pi - \theta_0)}{2}$$

$$\theta_2 = \begin{cases} \frac{\theta_1}{\pi} + \theta_0 & \alpha \leq (\pi - \theta_0)/2 \\ \alpha & \alpha > (\pi - \theta_0)/2 \end{cases}$$

Where:

P'' = acoustic power ~ watts

P = primary power ~ watts

W = power density at the transducer ~ watts/ft²

D = directivity ~ db

A = active area ~ ft²

S = source level ~ db

θ_0 = vertical dimension of active area ~ rad

ϕ = azimuthal dimension of active area ~ rad

r = radius of spherical shell array ~ ft

E_{TOT} = total efficiency of transducer and amplifier

α = depression angle.

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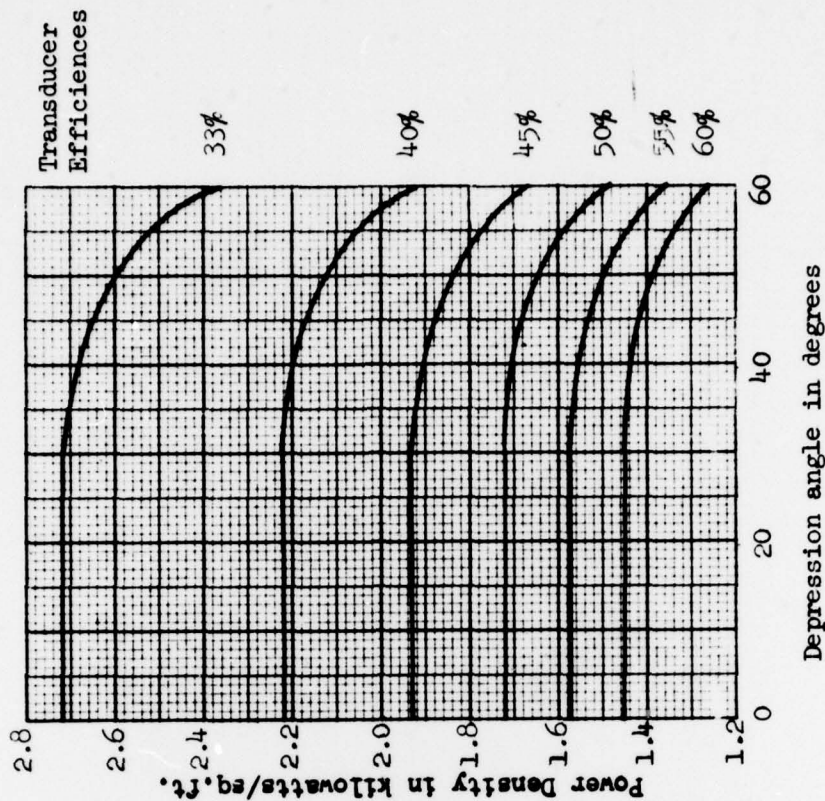


Figure 1

Power Density (W) input to transducer versus source levels of (S) 141, 145, and 150 dB re 1 μ bar for total efficiencies of .10 and .35.

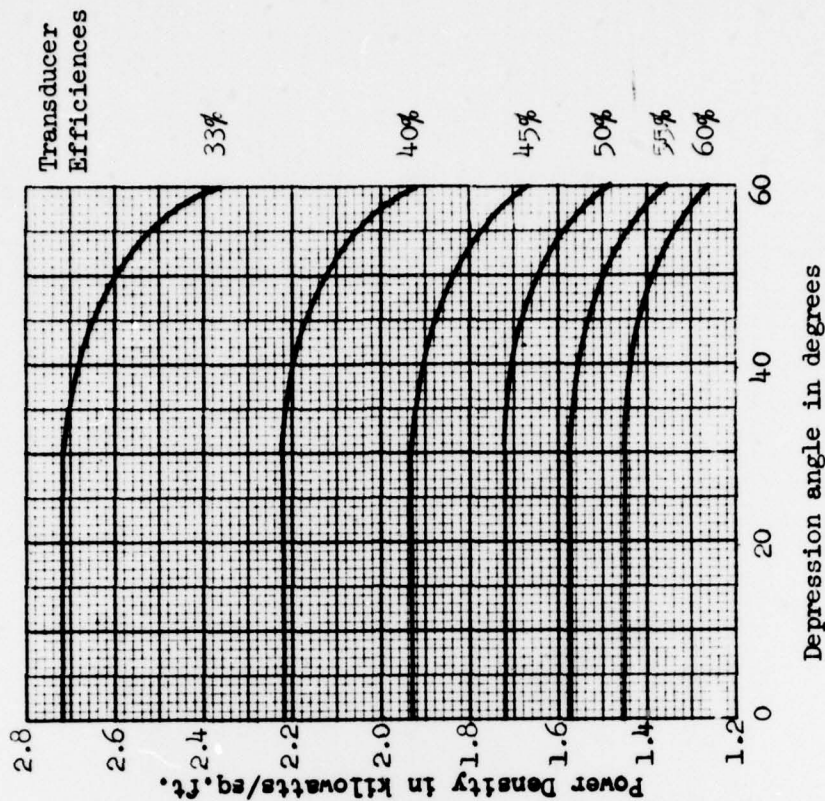


Figure 2

Power Density (W) input to the transducer versus total efficiencies (tot eff) of transducers and power amplifiers for a source level of 141 dB.

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Addendum

The power density discussed in this report is an average value.
Because the radiation impedance varies across the array, some elements
in the array may be handling five times the power of other elements.
This factor must be considered in any practicable design.

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